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Radiation And Chemical Reaction Effects Of Mass Transfer And Hall Current On Unsteady MHD Flow Of A Viscoelastic Fluid In A Porous Medium with Heat Generation

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Abstract: This study investigated the radiation and chemical reaction effects of mass transfer and Hall current on unsteady MHD flow of a viscoelastic fluid in a porous medium with heat generation. The resultant equations have been solved analytically. The velocity, temperature and concentration distributions are derived, and their profiles for various physical parameters are shown through graphs. The coefficient of Skin friction, Nusselt number and Sherwood number at the plate are derived and their numerical values for various physical parameters are presented through graphs. The influence of various parameters such as the thermal Grashof number, mass Grashof number, Schmidt number, Prandtl number, viscoelasticity parameter, the frequency of oscillation on the flow field and heat generation are discussed qualitatively.
Index Terms: Chemical reaction, MHD, Nusselt number, Thermal Grashof number, Viscoelasticity parameter,Heat generation.

I. Introduction:

Combined heat and mass transfer in fluid-saturated porous media finds applications in a variety of engineering processes such as heat exchanger devices, petroleum reservoirs, chemical catalytic reactors and processes, geothermal and geophysical engineering, moisture migration in a fibrous insulation and nuclear waste disposal and others. Lai and Kulacki [1] discussed the coupled heat and mass transfer by mixed convection from a vertical plate in a saturated porous medium. Many problems of Darcian and non-Darcian mixed convection about a vertical plate had been reported, as in Hsu and Cheng [2], Vafai and Tien [3]. Bejan and Khair[4] investigated the free convection boundary layer flow in a porous medium owing to combined heat and mass transfer.

Magnetohydrodynamic (MHD) flows have applications in meteorology, solar physics, cosmic fluid dynamics, astrophysics, geophysics and in the motion of earths core. In addition from the technological point of view, MHD free convection flows have significant applications in the field of stellar and planetary magnetospheres, aeronautical plasma flows, chemical engineering and electronics. Raptis [5] studied mathematically the case of time varying two dimensional natural convective flow of an incompressible, electrically conducting fluid along an infinite vertical porous plate embedded in a porous medium. Helmy [6] analyzed MHD unsteady free convection flow past a vertical plate embedded in a porous medium. Elabashbeshy [7] studied heat and mass transfer along a vertical plate in the presence of magnetic field. Chamkha and Khaled [8] investigated the problem of coupled heat and mass transfer by MHD free convection from an inclined plate in the presence of internal heat generation or absorption.

In the context of space technology and in the processes involving high temperature, the effects of radiation are vital importance. Recent developments in hypersonic flights, missile re-entry, rocket, rocket combustion chambers, power plants for inter planetary flight and gas cooled nuclear reactors, have focused attention on thermal with laminar free convection heat transfer from a vertical plate was investigate by Cess [9] for an absorbing, emitting fluid in the optically thick region, using the singular perturbation technique. Arpaci[10] considered a similar problem in both the optically thick regions and used the approximate integral technique and firstorder profiles to solve the energy equation. Raptis [11] analyzed the thermal radiation and free convection flow through a porous medium bounded by a vertical infinite porous plate by using a regular perturabation technique. Mohammed Ibrahim and Bhaskar Reddy [12] studied the effects of radiation and mass transfer effects on MHD free convection flow a long a stretching surface with

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viscous dissipation and heat generation. Damesh et.al [13] found the similarity analysis of magnetic field and radiation effects on forced convection flow.

The study of heat generation or absorption effects in moving fluids is important in the view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Vajravelu and Hadjinicolaou[14] studied the heat transfer characteristics in the laminar boundary layer of a viscous fluid over a stretching sheet with viscous dissipation or frictional heating and internal heat generation. Hossain *et al.*[15] studied problem of the natural convection flow along a vertical wavy surface with uniform surface temperature in the presence of heat generation/absorption. Alam *et al.*[16] studied the problem of the free convection heat and mass transfer flow past an inclined semi-infinite heated surface of an electrically conducting and steady viscous incompressible fluid in the presence of magnetic field and heat generation. Chamkha[17] investigated unsteady convective heat and mass transfer past a semi-infinite porous moving plate with heat absorption. Bala Anki Reddy and Bhaskar Reddy [18] found that the finite difference analysis of radiation effects on unsteady MHD flow of a chemically reacting fluid with timedependent suction. In many chemical engineering processes, there does occur the chemical reaction between foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications viz., Polymer production, manufacturing of ceramics or glassware and food procession. Muthucumaraswamy and Ganesan [19] studied the effects of suction on heat and mass transfer along a moving vertical surface in the presences of a chemical reaction. Mohammed Ibrahim et.al [20] analyzed the effects on the radiation and chemical reaction effects on MHD convective flow past a moving vertical porous plate. Das and Jana [21] examined Heat and Mass transfer effects on unsteady MHD free convection flow near a moving vertical plate in a porous medium. Exact Solution of MHD free convection flow and Mass Transfer near a moving vertical porous plate in the presence of thermal radiation was investigated by Das [22]. Sonth *et al.* [23] studied Heat and Mass transfer in a viscoelastic fluid over an accelerated surface with heat source/sink and viscous dissipation. Shateyi *et al.* [19] investigated the effects of thermal Radiation, Hall currents, Soret and Dufour on MHD flow by mixed convection over vertical surface in porous medium.

The objective of this paper was to explore the effects of Radiation And Chemical Reaction Effects Of Mass Transfer And Hall Current On Unsteady MHD Flow Of A Viscoelastic Fluid In A Porous Medium with Heat Generation. The temperature and concentration of the plate is oscillating with time about a constant nonzero mean value. The dimensionless governing equations involved in the present analysis are solved using a closed analytical method and discussed qualitatively and graphically.

II. Mathematical Formulation:

We consider the unsteady flow of a viscous incompressible and electrically conducting viscoelastic fluid over an infinite porous plate with oscillating temperature and mass transfer. The x-axis is assumed to be oriented vertically upwards along the plate and the y-axis is taken normal to the plane of the plate. It is assumed that the plate is electrically non – conducting and a uniform magnetic field of straight is applied normal to the plate. The induced magnetic field is assumed constant. So that $B=(0, B_0, 0)$ the plate is subjected to a constant suction velocity. The governing equations for the momentum, energy and concentration are as follows:

$$\frac{\partial u}{\partial t}+v_0\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}-K_1\frac{\partial^3 u}{\partial y^2\partial t}-\sigma B_0^2\frac{(u+mw)}{\rho(1+m^2)}+g\beta(T-T_\infty)+g\beta'(C-C_\infty)-\frac{v}{k'}u \quad (1)$$

$$\frac{\partial w}{\partial t}+v_0\frac{\partial w}{\partial y}=v\frac{\partial^2 w}{\partial y^2}-K_1\frac{\partial^3 w}{\partial y^2\partial t}-\sigma B_0^2\frac{(w-mu)}{\rho(1+m^2)}-\frac{u}{k'}w \quad (2)$$

$$\frac{\partial T}{\partial t}+v_0\frac{\partial T}{\partial y}=\frac{k_T}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}+\frac{Q}{\rho C_p}(T-T_\infty) \quad (3)$$

$$\frac{\partial C}{\partial t}+v_0\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-K'_r(C-C_\infty) \quad (4)$$

The appropriate boundary conditions for the problem are

u=0, *w=0,*

$$T=T_\infty+(T_\omega-T_\infty)e^{\text{int}},\ C=C_\infty+(C_\omega-C_\infty)e^{\text{int}},$$

at y=0

$$u\to 0, w\to 0, T\to 0, C\to 0 \ as\ y\to\infty \quad (5)$$

g is the acceleration due to gravity, β and β′ are the coefficient of volume expansion, *k1* is the kinematic viscoelasticity, ϱ is the density, *v* is the kinematic viscosity, *kT* is the thermal conductivity, *Cp* is the specific heat in the fluid at constant pressure, σ is the electrical conductivity of the fluid, *K′* is the permeability, *Tw* is the temperature of the plane and T_∞ is the temperature of the fluid far away from plane, *Cw* is the concentration of the plane and C_∞ is the concentration of the fluid far away from the plane, *qr* is the radioactive heat flux and K_r' is the chemical reaction and D is the molecular diffusivity. And, $v = -v_0$ the negative sign indicate that the suction is towards the plane.

By using the Rosseland approximation, the radioactive flux vector q_r can be written as:

$$q'_r = -\frac{4\sigma'}{3K'_1}\frac{\partial T_w'^4}{\partial y'} \qquad (6)$$

Where, σ' and k'_1 are respectively the Stefan-Boltzmann constant and the mean absorption coefficient. We assume that the temperature difference within the flow is sufficiently small such that T'^4 may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about the free stream temperature T'_∞ and neglecting higher order terms

$$T_w'^4 \cong 4T_\infty'^3 T_w' - 3T_\infty'^4 \qquad (7)$$

In view of equations (6) and (7), Equation (3) reduces to:

$$\frac{\partial T}{\partial t} + v_0\frac{\partial T}{\partial y} = \frac{k_T}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - \frac{16\sigma' T'_\infty}{3k'_1\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho C_p}(T - T_\infty) \qquad (8)$$

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensional quantities are introduced.

$$u = \frac{u'}{u_0}, \eta = \frac{v_0 y}{v}, t' = \frac{t v^2{}_0}{4v}, w' = \frac{wv}{v_0^2}, N = \frac{k_1' k}{4\sigma' T_\infty'^3}, K = \frac{K' v_0^2}{v^2}, n = \frac{n' v}{v_0^2}$$
$$\theta = \frac{T - T_\infty'}{T_w' - T_\infty'}, \phi = \frac{C - C_\infty}{C_w - C_\infty}, K = \frac{K_1 v_0^2}{4v^2}, pr = \frac{v\rho c_p}{k}, Kr = \frac{K_r' v}{v_0^2}, Sc = \frac{v}{D},$$
$$M = \frac{\sigma B_0^2 v}{\rho v_0^2}, Gr = \frac{v\beta g(T' - T_\infty')}{v_0^3}, Gc = \frac{v\beta' g(C' - C_\infty')}{v_0^3}, Q = \frac{Q_0 v(T' - T_\infty')}{k\,\mathrm{Pr}} \qquad (9)$$

Substituting the dimensionless variables in (9) into (1), (2), (8), (4) and (5),

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial \eta} = \frac{\partial^2 u}{\partial \eta^2} - \frac{k}{4}\frac{\partial^3 u}{\partial \eta^2 \partial t} - \frac{M(u + mw)}{(1 + m^2)} - \frac{1}{k}u + Gr\theta + Gc\phi \qquad (10)$$

$$\frac{1}{4}\frac{\partial w}{\partial t} - \frac{\partial w}{\partial \eta} = \frac{\partial^2 w}{\partial \eta^2} - \frac{k}{4}\frac{\partial^3 w}{\partial \eta^2 \partial t} - \frac{M(w - mw)}{(1 + m^2)} - \frac{1}{k}u \qquad (11)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial \eta} = \frac{1}{pr}\left(1 + \frac{4}{3N}\right)\frac{\partial^2 \theta}{\partial \eta^2} + Q\theta \qquad (12)$$

$$\frac{1}{4}\frac{\partial \phi}{\partial t} - \frac{\partial \phi}{\partial \eta} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial \eta^2} - Kr\phi \qquad (13)$$

The corresponding boundary conditions are

u = 0, w = 0, $\theta = e^{int}$ at $\eta = 0$ and $u \to 0$, $w \to 0$, $\theta \to 0$ as $\eta \to \infty$ (14)

Equations (10) and (11) can be combined into a single equation by introducing the complex velocity

$U = u(\eta, t) + iw(\eta, t)$, (15)

where $i = \sqrt{-1}$, Thus,

$$\frac{1}{4}\frac{\partial U}{\partial t} - \frac{\partial U}{\partial \eta} = \frac{\partial^2 U}{\partial \eta^2} - \frac{k}{4}\frac{\partial^3 u}{\partial \eta^2 \partial t} - \frac{M(1 - im)U}{(1 + m^2)} - \frac{U}{k} + Gr\theta + Gc\phi \qquad (16)$$

With the boundary conditions

U = 0, $\theta = e^{int}$, $\varphi = e^{int}$ at $\eta = 0$ and $u \to 0$, , $\theta \to 0$, $\emptyset \to 0$ as $\eta \to \infty$ (17)

Where *Gr, Gc, k, Pr, Kr, Sc, N, Q* are the thermal Grashof number, modified Grashof number, viscoelastic parameter, Prandtl number, Chem ical reaction number, Schmidt number and radiation parameter and heat generation respectively.

III. Solution of the Problem:

In order to reduce the above system of partial differential equations to a system of ordinary differential equations in dimensionless form, we assume the trial solution for the velocity, temperature and concentration as:

$$U(\eta, t) = U_0(\eta)e^{\mathrm{int}} \qquad (18)$$

$$\theta(\eta, t) = \theta_0(\eta)e^{\mathrm{int}} \qquad (19)$$

$$\phi(\eta, t) = \phi_0(\eta)e^{\mathrm{int}} \qquad (20)$$

Substituting Equations (18), (19) and (20) in Equations (16), (14) and (15), we obtain:

$$P_1 U_0'' - U_0' - P_2 U_0 = -Gr\theta_0 - Gc\phi_0 \qquad (21)$$

$$P_3\theta_0'' + \theta_0' - \left(\frac{in}{4} - Q\right)\theta_0 = 0 \qquad (22)$$

$$\phi_0'' + Sc\phi_0' - \left(Kr + \frac{in}{4}\right)Sc\phi_0 = 0 \qquad (23)$$

Here the primes denote the differentiation with respect to η.The corresponding boundary conditions can be written as

$U_0 = 0$, $\theta_0 = 1$, $\phi_0 = 1$ at $\eta = 0$ and $U_0 \to 0$, $\theta_0 \to 0$, $\phi_0 \to 0$ as $\eta \to \infty$ (24)

The analytical solutions of equations (21) – (23) with satisfying the boundary conditions (24) are given by

$$U_0(\eta) = A_1 e^{-m_2 y} + A_2 e^{-m_1 y} + A_3 e^{-m_3 y} \qquad (25)$$

$$\theta_0(\eta) = e^{-m_1 y} \qquad (26)$$

$$\phi_0(\eta) = e^{-m_2 y} \qquad (27)$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer become

$$U_0(\eta, t) = \left\{A_1 e^{-m_2 y} + A_2 e^{-m_1 y} + A_3 e^{-m_3 y}\right\}e^{\mathrm{int}} \qquad (28)$$

$$\theta_0(\eta, t) = (e^{-m_1 y})e^{\mathrm{int}} \qquad (29)$$

$$\phi_0(\eta, t) = (e^{-m_2 y})e^{\mathrm{int}} \qquad (30)$$

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The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flows.

Skin friction: Knowing the velocity field, the skin –friction at the plate can be obtained, which in non –dimensional form is given by

$$Cf=\left[-\frac{\partial u}{\partial \eta}\right]_{\eta=0}=\{A_1 m_2+A_2 m_1+A_3 m_3\}e^{\text{int}}$$

Nusselt number: Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non –dimensional form is given, in terms of the Nusselt number, is given by

$$Nu=\left[-\frac{\partial \theta}{\partial \eta}\right]_{\eta=0}=m_2 e^{\text{int}}$$

Sherwood number: Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non –dimensional form, in terms of the Sherwood number, is given by

$$Sh=\left[-\frac{\partial \phi}{\partial \eta}\right]_{\eta=0}=m_1 e^{\text{int}}$$

$$P_1=1-\frac{Kin}{n},\ P_2=\left[\frac{M(1-im)}{1+m^2}+\frac{1}{k}+\frac{in}{4}\right],\ P_3=\frac{1}{pr}\left(1+\frac{4}{3N}\right)$$

Where

$$m_1=\frac{Sc+\sqrt{Sc^2-4\left(\frac{Kr+in}{4}\right)}}{2},$$

$$m_2=\frac{1+\sqrt{1+4P_3\left(\frac{in}{4}-Q\right)}}{2P_3},$$

$$m_3=\frac{1+\sqrt{1+4P_2P_1}}{2P_1}$$

$$A_1=\frac{-Gr}{p_1 m_2{}^2+m_2-P_2},$$

$$A_1=\frac{-Gc}{p_1 m_1{}^2+m_1-P_2},\qquad A_3=-(A_1+A_2)$$

V. Results and Discussion :

The effect of mass transfer and Hall current on unsteady MHD flow of a viscoelastic fluid in a porous medium has been formulated and solved analytically. In order to understand the flow of the fluid, computations are performed for different parameters such as *M, m, Gr, Gc, Pr, Sc, K, k, N ,Q* and *Kr*. Figures 1-8 represent the velocity profiles, figures 9 and 10 depict the temperature profiles and figures 11 and 12 show the concentration profiles with varying parameters respectively.

Fig-1 depicts the effect of velocity for different values of Hartmann number M. It is observed that the graph shows that velocity decreases with an increasing M. The effects of velocity profiles are for different values of *m* as shown in Fig.2. It is noticed that the velocity decreases with an increasing m. The effect of velocity for different values of Grashof number Gr is presented in Fig.3. It is seen that the velocity increases with an increases in Gr. The effect of velocity profiles for different values of modified Grashof number Gc is displayed in Fig.4. It is observed that velocity increases with the increase in Gc. The effect of velocity profiles for different values of Prandtl number Pr is presented in Fig.5. It is observed that the velocity decreases with increase in Pr. The effect of velocity for different values of Schmidt number Sc is given in Fig.6. It is noticed that the graph show that velocity decreases with the increase in Sc. Fig.7 denotes the effect of velocity for different values of viscoelastic parameter *K*. It is seen that velocity increases with the increase in *K*. The effect of velocity profiles for different values of permeability parameter *k* is shown in Fig.8. It is observed that velocity increases with the increase in *k*. In Fig. 9, the velocity profiles are presented for different values radiation parameter N. It is observed that the radiation parameter is increases, the velocity profiles also increases. Fig-10. Velocity profiles for different values of heat generation parameter Q. It is observed that the heat generation parameter is increases, the velocity profiles also increases. Fig-11. Temperature profiles for different values of N. It is observed that temperature decreases with increase in N. Fig-12. Temperature profiles for different values of n depicts that temperature decreases with increase in n. Fig-13. Temperature profiles for different values of Pr . it is observed that temperature increases with increase in Pr. Fig-14. Temperature profiles for different values of Q it depicts that the temperature increases with the increase in heat generation. Fig-15. Concentration profiles for different values of n it is observed that concentration decreases with the increase in n. Fig-16. Concentration profiles for different values of Sc it is observed that concentration decreases with the increase in Schmidt number.

From Table.1 shows the increase in magnetic field parameter increase in the skin friction. Table.2 indicates the increase in radiation parameter shows the increase in the skin friction and Nusselt number. Table.3 shows the increase in Schmidt number shows the increase in sherwood number. .Table 4. Displays the increase in Prandtl number displays the increase in skin friction and Nusselt number. Table-5. Effects of heat generation shows the decrease in skin friction and Nusselt number.

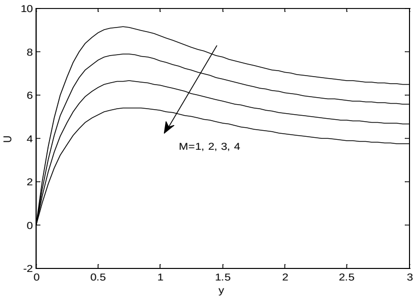

Fig-1. Velocity profiles for different values of M.

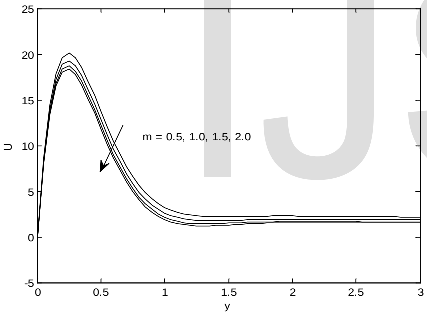

Fig-2. Velocity profiles for different values of m.

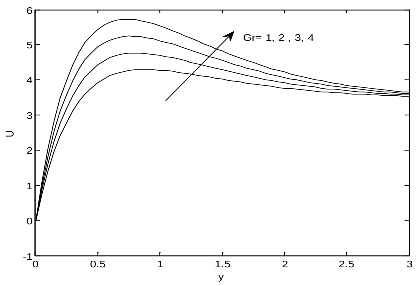

Fig-3. Velocity profiles different values for of Gr.

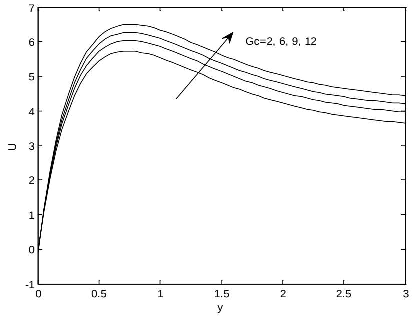

Fig-4. Velocity profiles for different values of Gc.

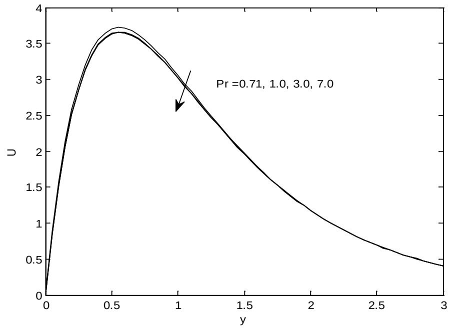

Fig-5. Velocity profiles for different values of Pr.

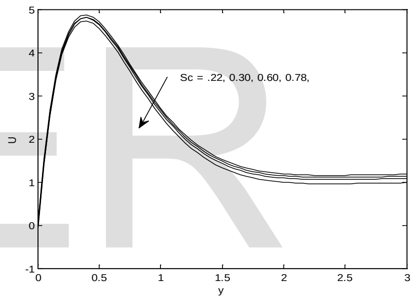

Fig-6. Velocity profiles for different values of Sc.

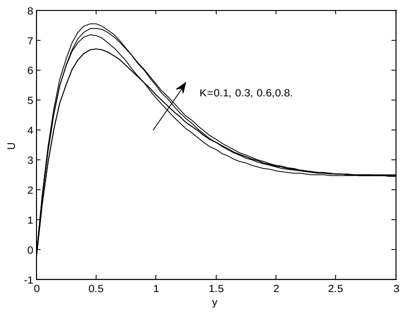

Fig-7. Velocity profiles for different values of K.

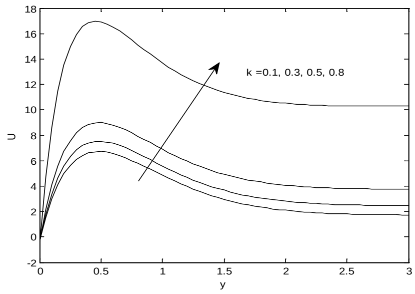

Fig-8. Velocity profiles for different values of k.

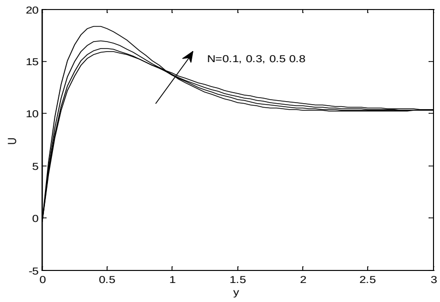

Fig-9. Velocity profiles for different values of N.

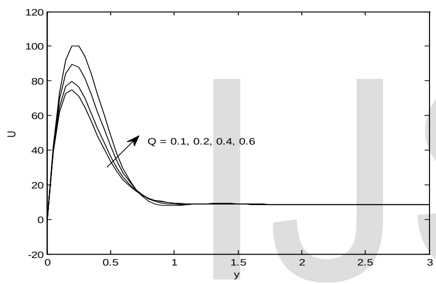

Fig-10. Velocity profiles for different values of Q.

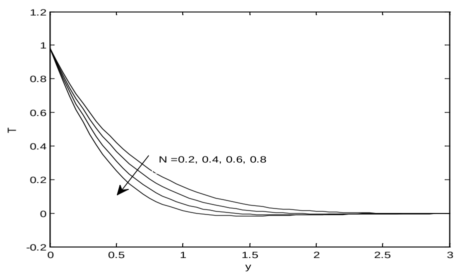

Fig-11. Temperature profiles for different values of N.

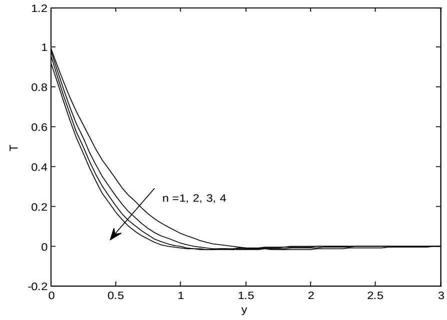

Fig-12. Temperature profiles for different values of n.

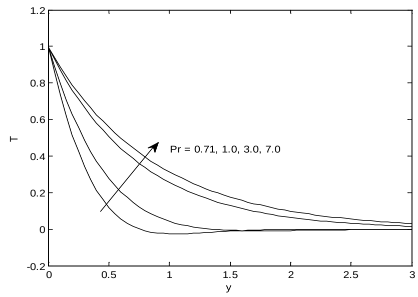

Fig-13. Temperature profiles for different values of Pr.

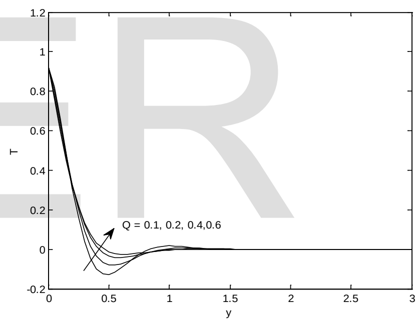

Fig-14. Temperature profiles for different values of Q.

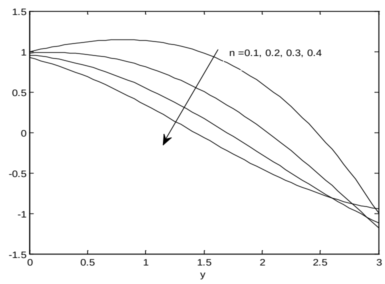

Fig-15. Concentration profiles for different values of n.

Q	Cf	sh
0.1	37.0823	2.1429
0.2	42.4156	1.8857
0.3	46.4970	1.6946
0.4	49.5905	1.5493

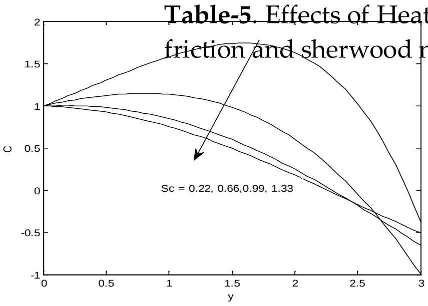

Fig-16. Concentration profiles for different values of Sc.

Table-1. Effects of magnetic parameter on skin friction.

Table-2. Effects of Radiation parameter on skin friction and nusselt number.

R	Cf	Nu
0.5	-1.4023	1.4171
1.0	-1.4627	1.7391
1.5	-1.5578	2.0351
2.0	-1.6589	2.8092

Table-3. Effects of Schmidt number on sherwood number.

Table-4. Effects of Prandtl number on skin friction and Nusselt number.

Pr	Cf	Nu
0.71	1.5287	1.8588
1.00	49.5905	1.5493
5.00	15.9891	1.1317
7.00	15.899	1.1108

Table-5. Effects of Heat generation prameter on skin friction and sherwood number.

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M	Cf
1.0	36.5179
1.2	39.1830
1.3	41.7571
1.4	44.2518

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Sc	Sh
0.22	-0.0258
0.30	-0.0529
0.60	-0.3440
0.78	-0.5143

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